RT Modelling of CMEs Using WSA-ENLIL Cone Model

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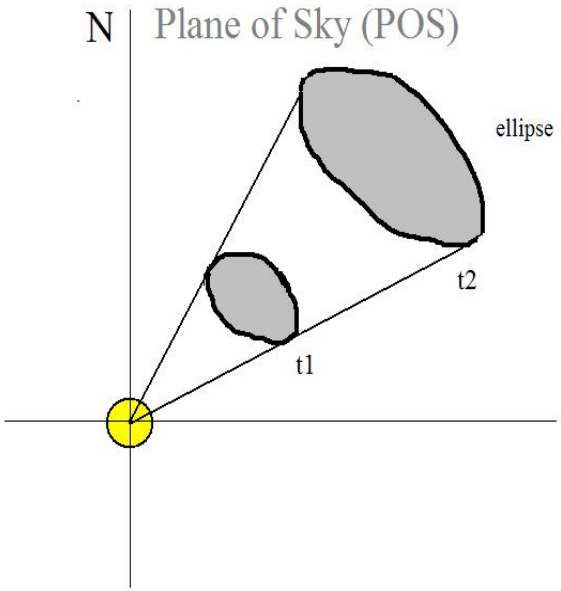
Cone Model for CMEs

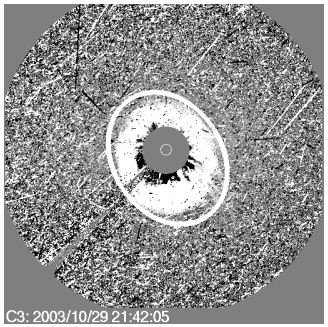
Zhao et al, 2002, Cone Model:

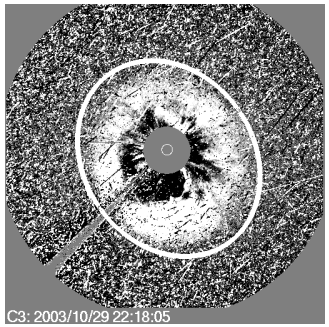


The projection of the cone on the POS is an ellipse

The CME cone model is based on observational evidence that CME has more or less constant angular diameter in corona, being confined by the external magnetic field, so that CME does not expand in latitude in the lower corona, but expands in interplanetary space because of the weaker external field

•CME bulk velocity is radial and the expansion is isotropic

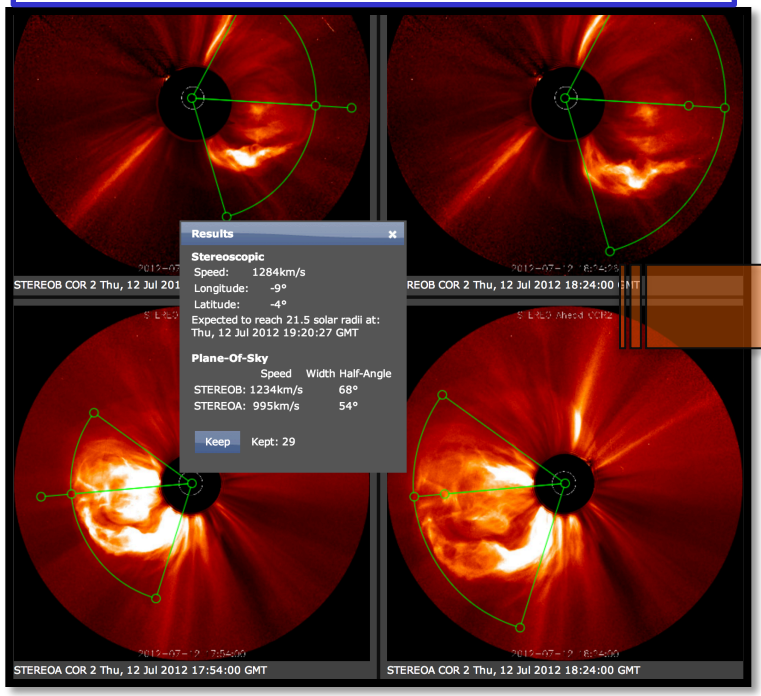




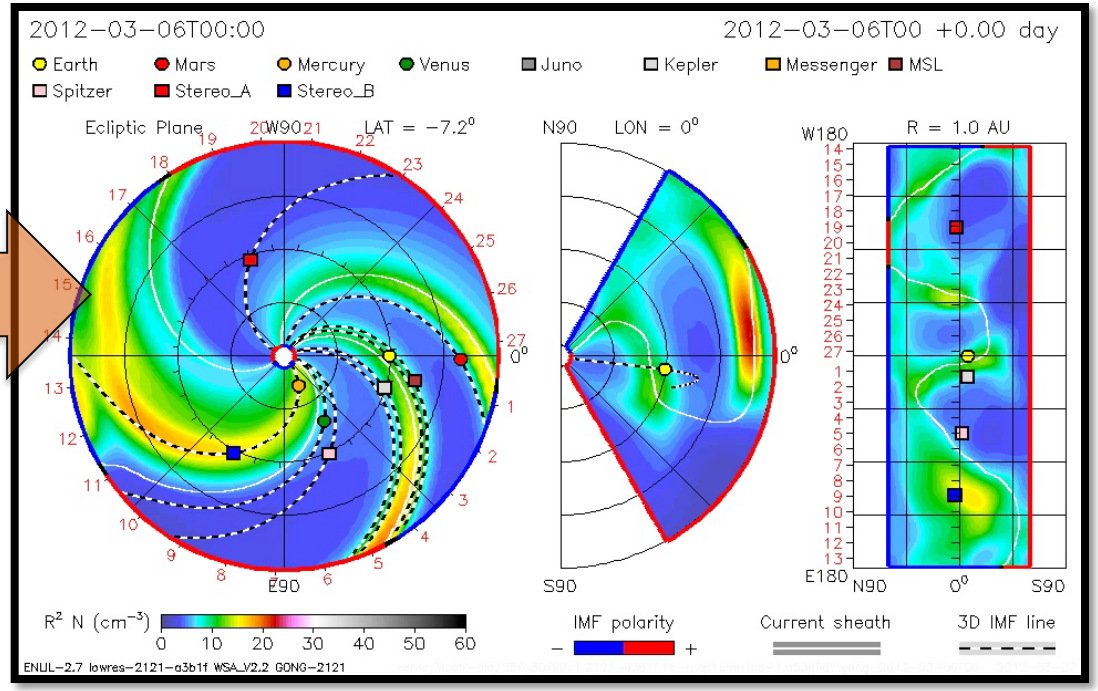
CME V and orientation
Input to WSA-ENLIL

WSA-ENLIL Cone Model

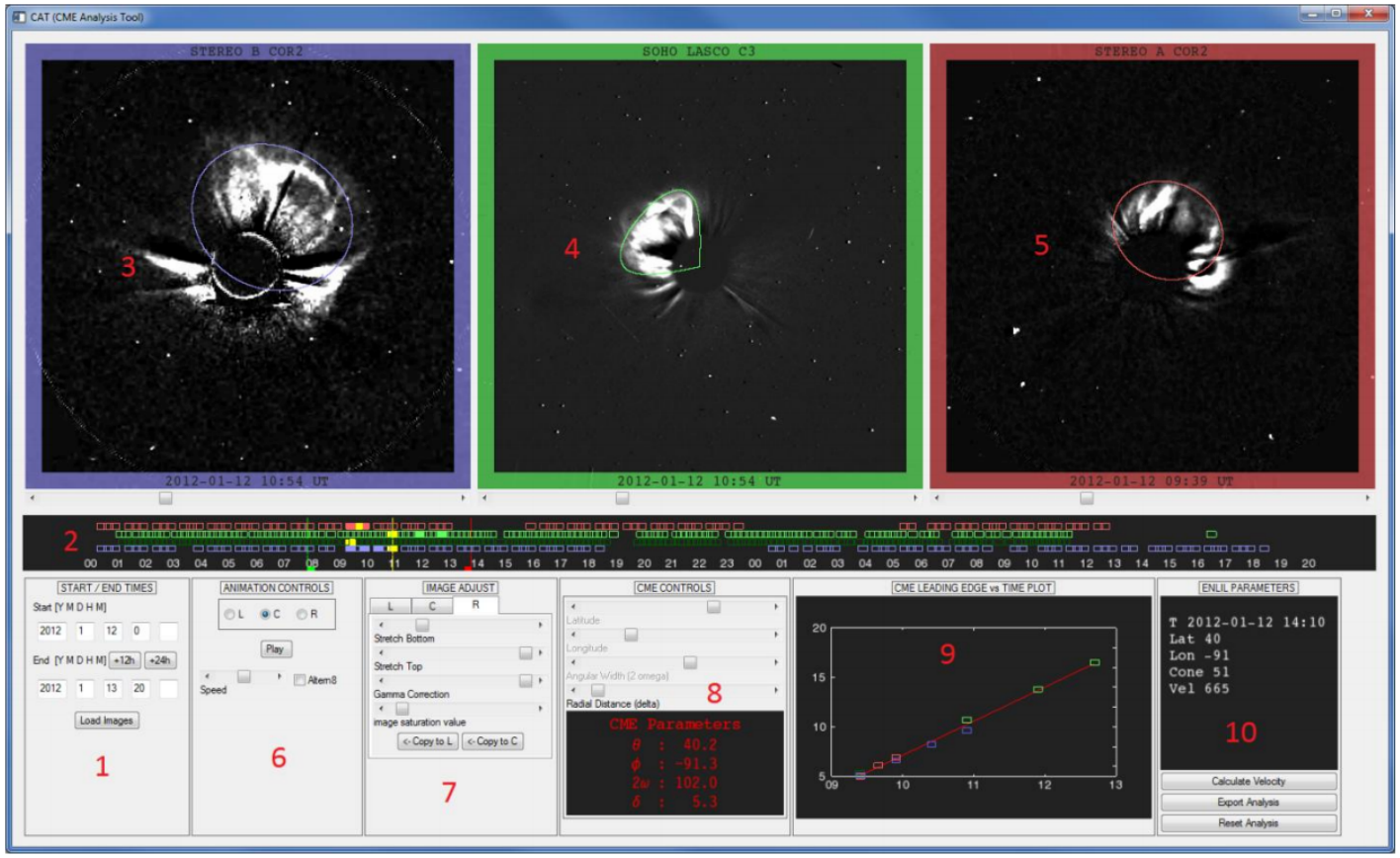
Parameters Defined with CCMC CME Triangulation Tool



CME Parameters: Input To WSA-ENLIL Cone Model

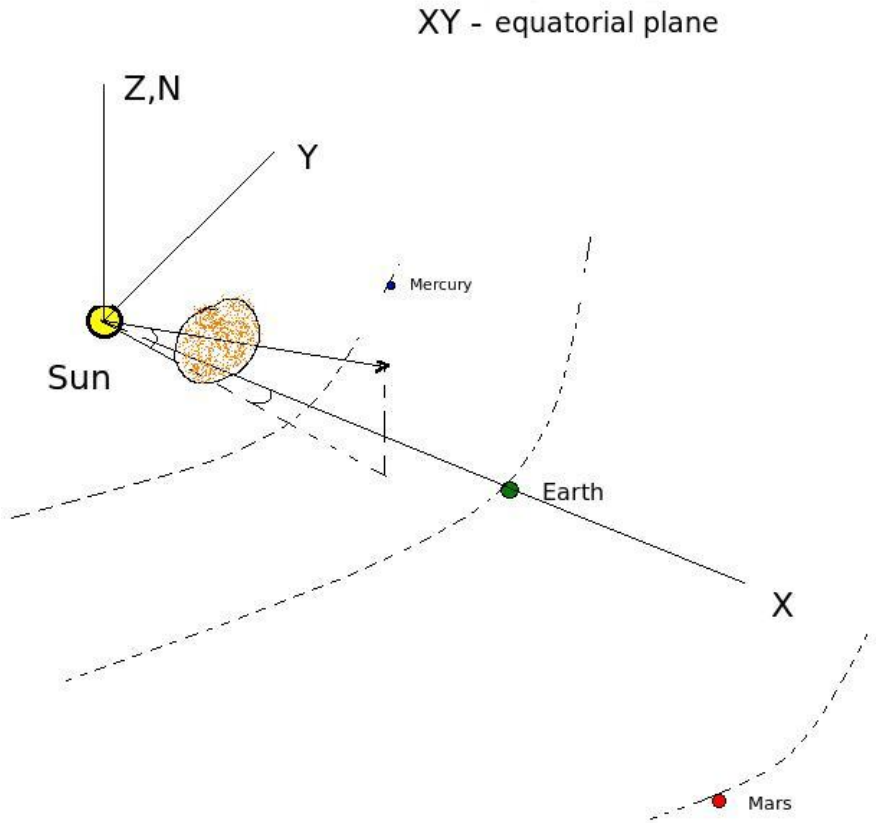


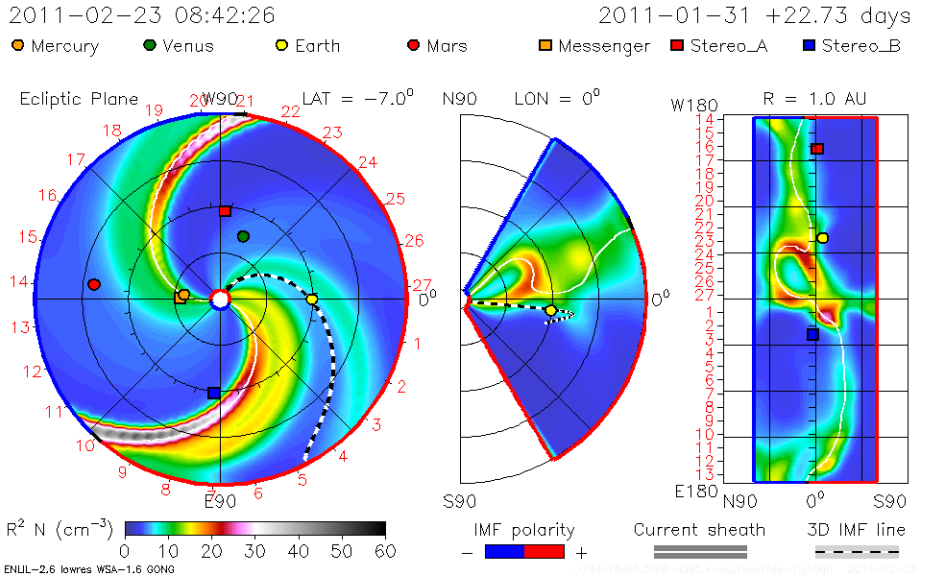
SWPC CME Analysis Tool



Sun, Planets, CME

Heliocentric Earth Equatorial Coordinates - Heliographic



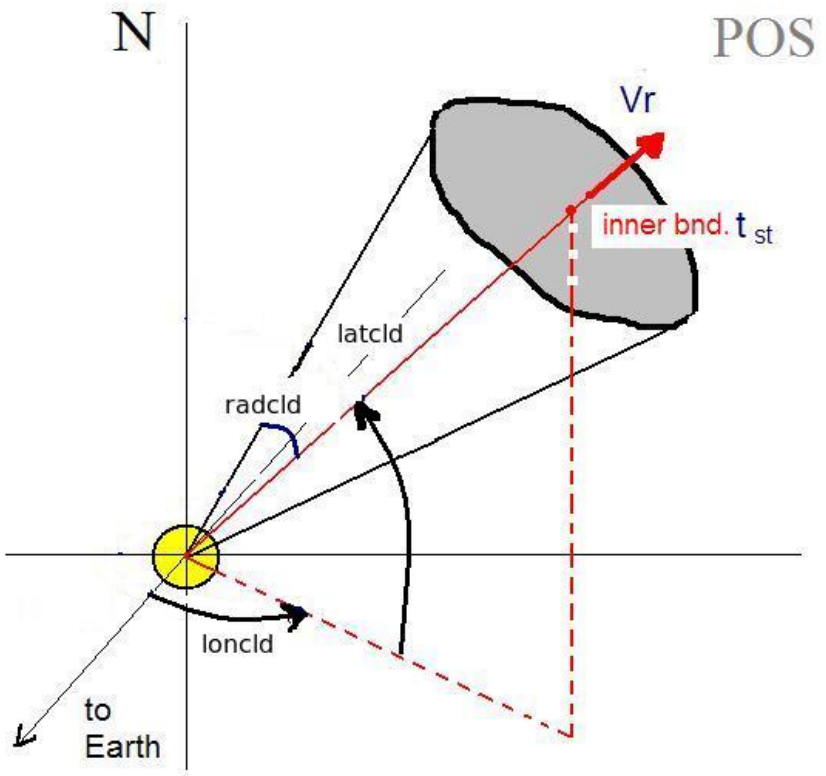


Constant Latitude Plane passing through Earth

Meridional Plane

1AU quasi-sphere

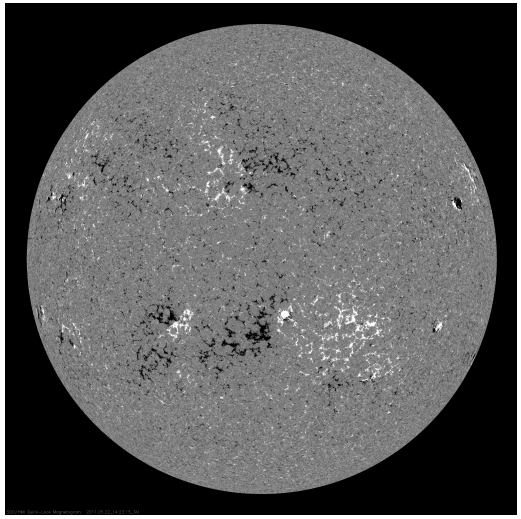
Cone model parameters



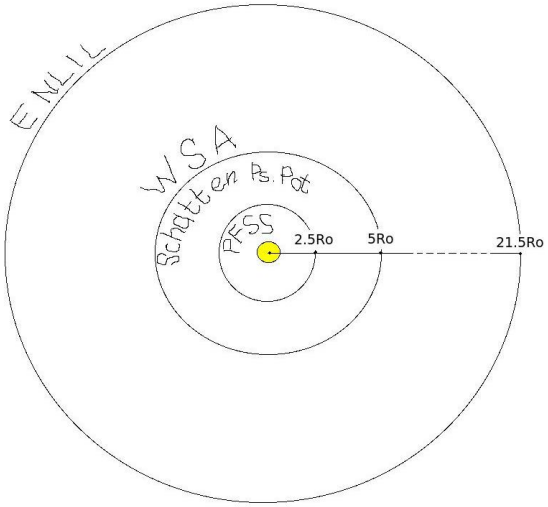
- tstart - when cloud at 21.5Rs
- Latitude
- Longitude
- Radius (angular width)
- Vr - radial velocity

Input to ENLIL cone model run

Wang Sheely Arge model (WSA) - SW Input to ENLIL @ 21.5 Rs



- **PFSS** (Potential Field Source Surface)**.**
  Input: synoptic map photospheric magnetogram.
  Force free (even current free) solution with radial field at 2.5 Ro.
- **Schatten Current Sheet**.
  Input: PFSS.
  Modifies the sign of radial field to positive to prevent reconnection, creates potential solution with radial boundary conditions, restores the sign in the new solution at 5 Ro.



Assuming radial constant speed flow at 5 Ro uses **empirical formula for speed,** determined by the rate of divergence of the magnetic field at 5 Ro and proximity of the given field line to the coronal hole boundary. **WSA produces Br and Vr – input to ENLIL**

ENLIL - Schematic Description

ENLIL – *Sumerian God of Winds and Storms*

Dusan Odstrcil, GMU & GSFC

Input: WSA (coronal maps of Br and Vr updated 4 times a day). For toroidal components at the inner boundary- Parker spiral (Parker model for the SW).

ENLIL's inner radial boundary is located **beyond the sonic point**: the solar wind flow is supersonic in ENLIL.

Computes a time evolution of the global solar wind for the inner heliosphere, driven by corotating background structure and transient disturbances (CMEs) at it's inner radial boundary at 21.5 Ro.

Solves ideal fully ionized plasma MHD equations in 3D with two additional continuity equations: for density of transient and polarity of the radial component of B.

ENLIL Schematic Description (cont.)

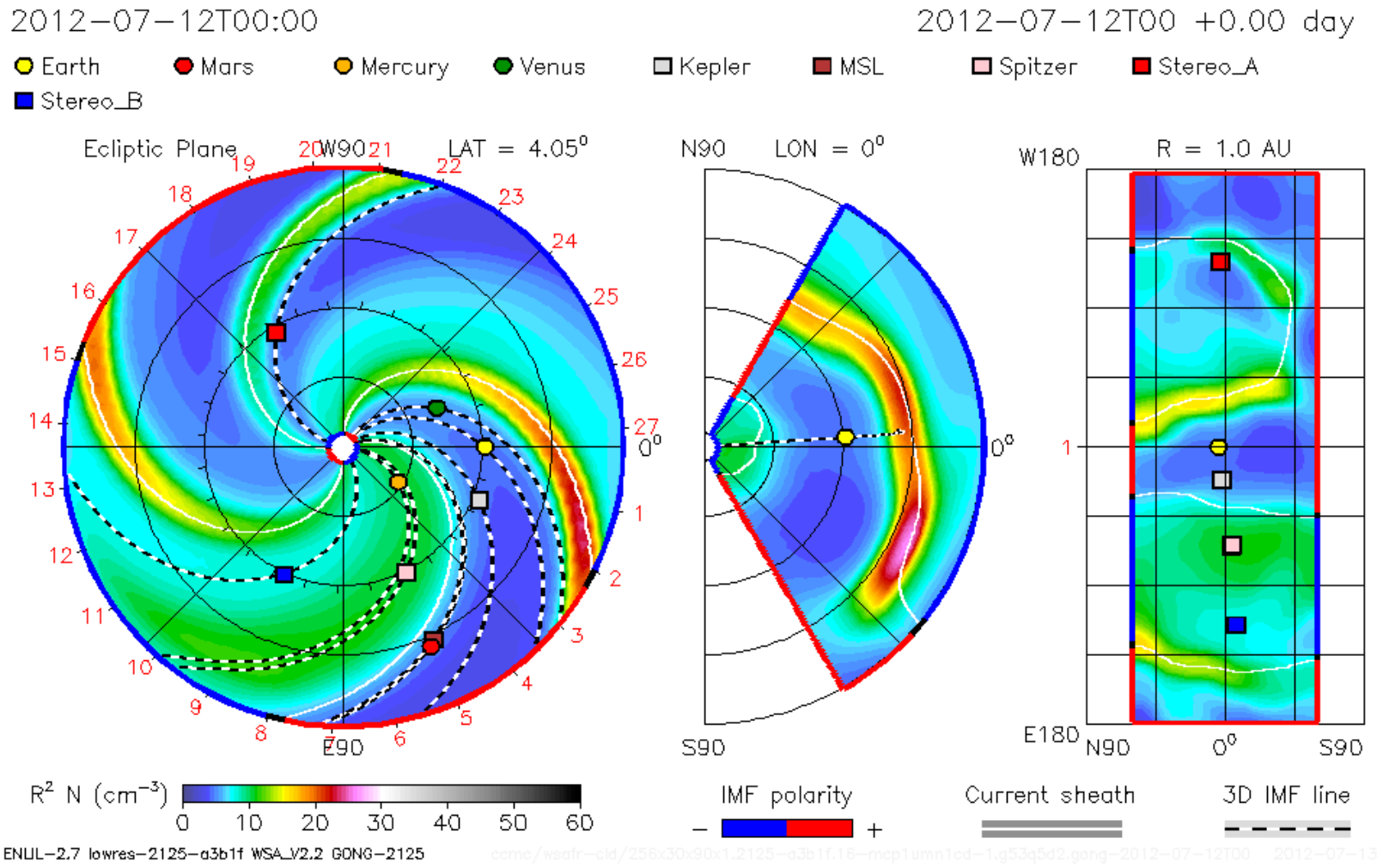
ENLIL model does not take into account the realistic complex magnetic field structure of the CME magnetic cloud and the CME as a plasma cloud has a uniform velocity.

It is assumed that the CME density is 4 times larger than the ambient fast solar wind density, the temperature is the same. Thus, the CME has about four times larger pressure than the ambient fast wind. Launching of an over pressured plasma cloud at 21.5 **Rs,** roughly represents CME eruption scenario

Output:

3D distribution of the SW parameters at spacecraft and planets and topology of IMF.

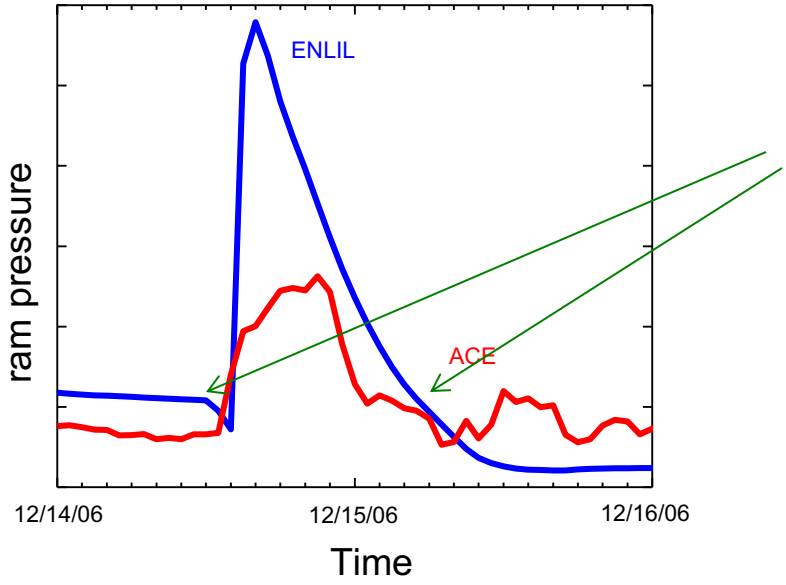
CME modeling



CME Impact – arrival, duration, MP standoff distance

CME shock arrival – a sharp jump in the dynamic pressure

$$nm_pV^2$$



Duration of the disturbance – duration of the dynamic pressure hump

Magnetic field required to stop SW

$$\frac{B_{stop}^2}{2\mu_0} = Knm_pV^2$$

→

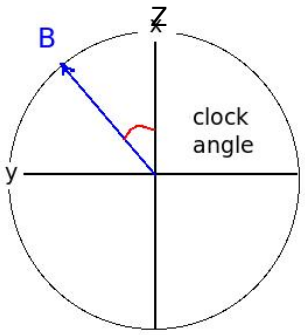
Magnetopause standoff distance

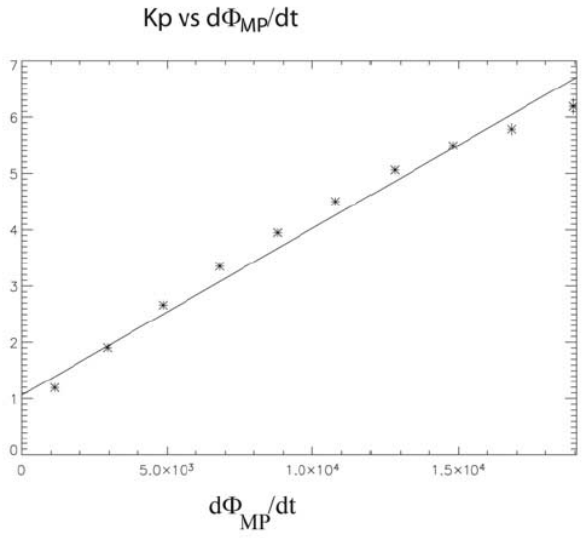
$$\frac{r_{mp}}{R_e} = \left(\frac{B_0}{B_{stop}}\right)^{1/3}$$

Kp Index – P. Newel's Empirical Expression

Magnetic flux opening rate at the magnetopause

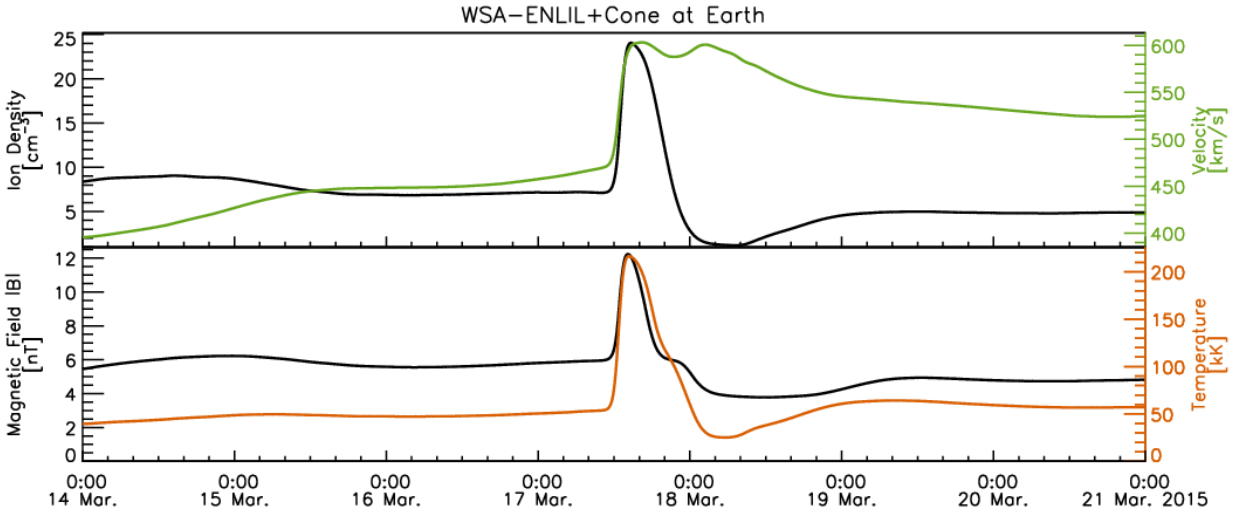
$$\frac{d\Phi_{MP}}{dt} = V^{4/3} B^{2/3} \sin^{8/3}(cl\ ang/2)$$

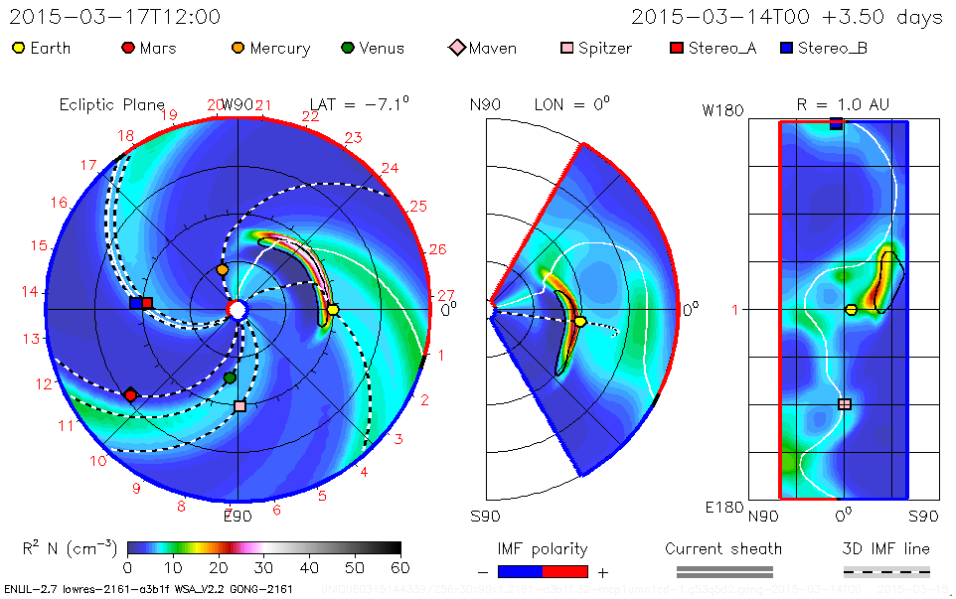




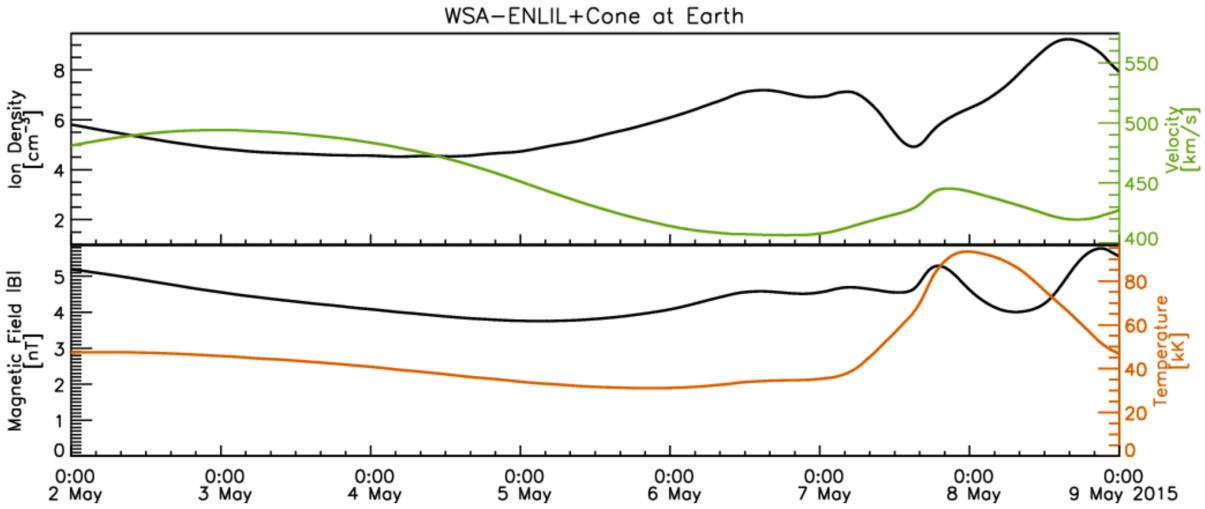
$$Kp = 9.5 - \exp\left(2.17676 - 0.000052001\frac{d\Phi_{MP}}{dt}\right)$$

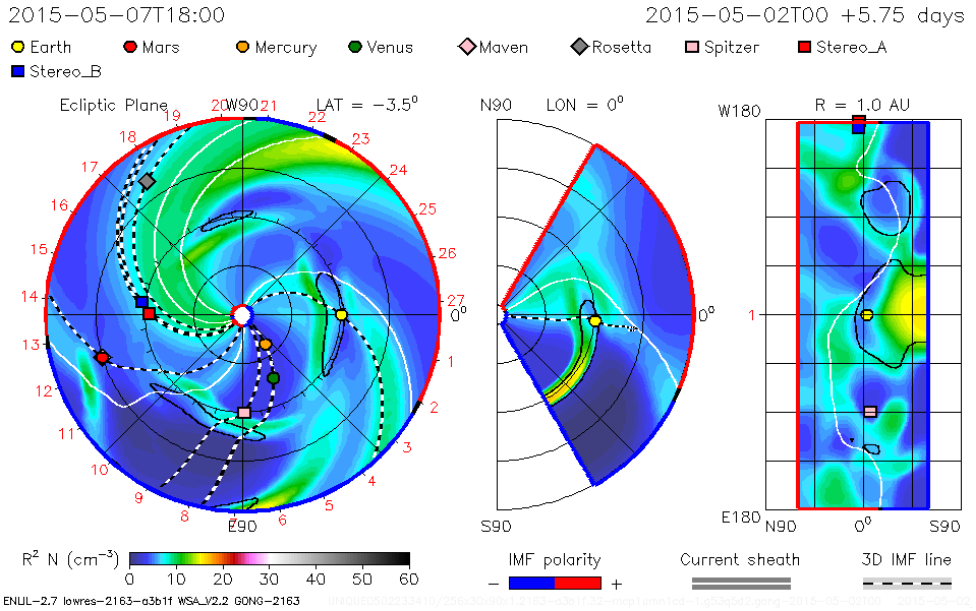
Determination of the CME Arrival Time – clear arrival





Determination of the CME Arrival Time from Timelines and Movies





e-mail with CME impact estimate at Earth

Arrival time(year/month/day, hr:min UT) =2012-07-31T15:02Z
(confidence level +-7 hours)

Duration of the disturbance (hr) = 10.3
(confidence level +-8 hours)

Minimum magnetopause standoff distance: Rmin(Re)=5.6
(under quiet conditions: Rmin(Re)=10;
R_geosynchr(Re)=6.6)

Kp index for three possible IMF clock angles
(angle 180 gives the maximum possible estimated Kp):
(Kp)_90=4
(Kp)_135=6
(Kp)_180=7

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Here are the links to the movies of the modeled event

http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-pdyn.gif

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_B.gif

Timelines
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_timeline.gif
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_Kp_timeline.gif

e-mail for NASA missions

Mars
****

CME did not hit the Mars.
or
CME impact is very weak.

****

Stereo A
****

CME did not hit the StereoA.
or
CME impact is very weak.

****

Stereo B
****
CME did not hit the StereoB.
or
CME impact is very weak.

****

Spitzer
****

Arrival time(year/month/day, hr:min UT) =2015-05-11T20:49Z

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_B.gif

Inner Planet Timelines
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Mars_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STA_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STB_timeline.gif
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http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Merc_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Venus_timeline.gif

Part 2:

RT Ensemble Modelling of CMEs Using WSA-ENLIL Cone Model

Why do you running of a single model is good enough to predict the CME arrival and impact?

Ensemble Modeling

Ensemble modeling is used in weather forecasting to quantify prediction uncertainties and determine forecast confidence

- Individual forecasts which constitute an ensemble forecast represent possible scenarios which reflects forecasting uncertainties.
- Uncertainties can be from initial conditions, observation error, and techniques and models.
- Different forecasts in the ensemble can start from different initial conditions and/or be based on different forecasting models/procedures.
- Ensemble modeling conveys the level of uncertainty in a given forecast in contrast to a categorical yes/no forecast

Ensemble Modeling with WSA-ENLIL+Cone

The current version of real-time ensemble modeling at the CCMC/SWRC evaluates the sensitivity of CME arrival time predictions from the model to initial CME parameters.

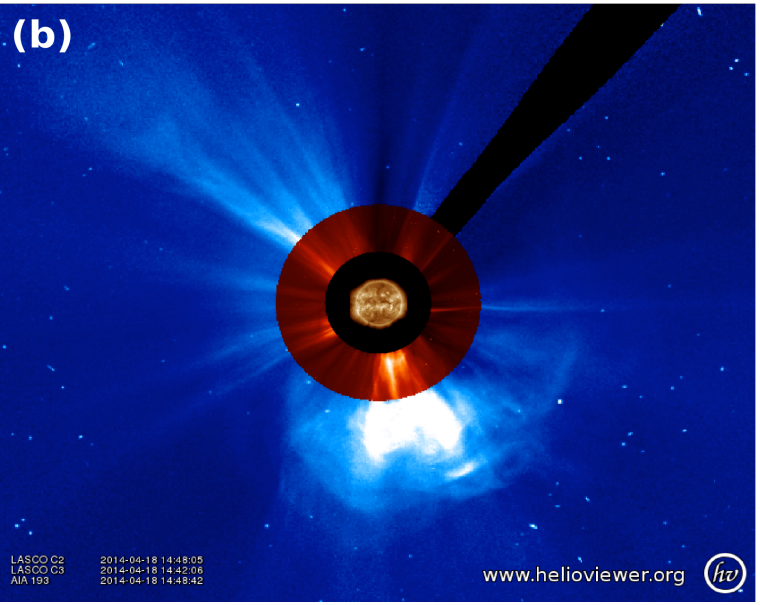
- Measure a set of *n* CME input parameters. Typically *n*=36 to 48 provides an adequate spread of input parameters, and this number can be increased as needed.

- These are used as input to an ensemble of *n* WSA-ENLIL+Cone model runs.

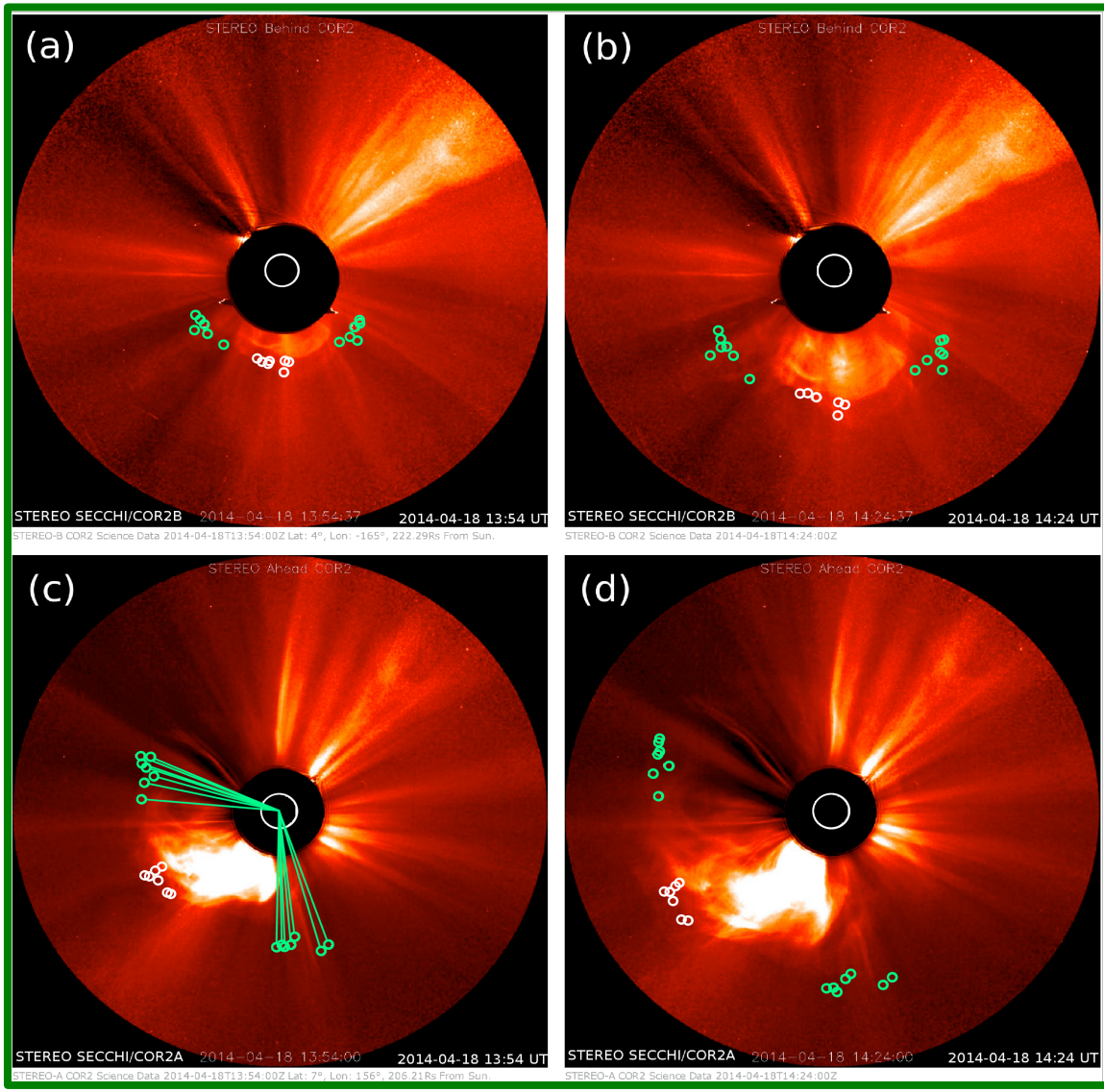
- This gives an ensemble of *n* profiles of MHD quantities and *n* CME arrival time predictions at locations of interest.

Example ensemble simulation: 18 April 2014 CME

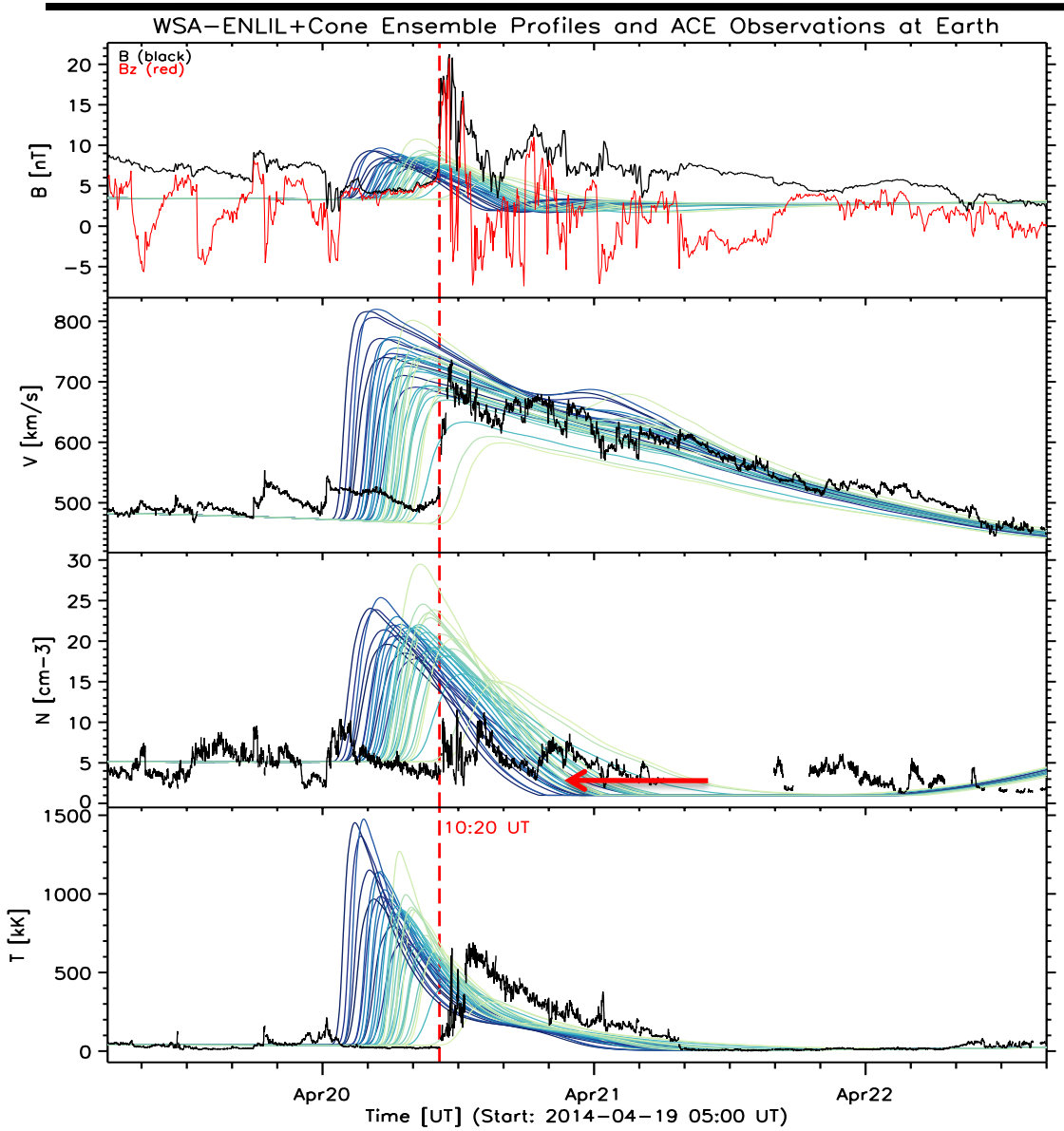
Halo CME associated with M7.3 flare, coronal wave visible south of the AR



Ensemble of input CME parameters obtained by measuring the same feature using StereoCAT, which employs geometric triangulation techniques.

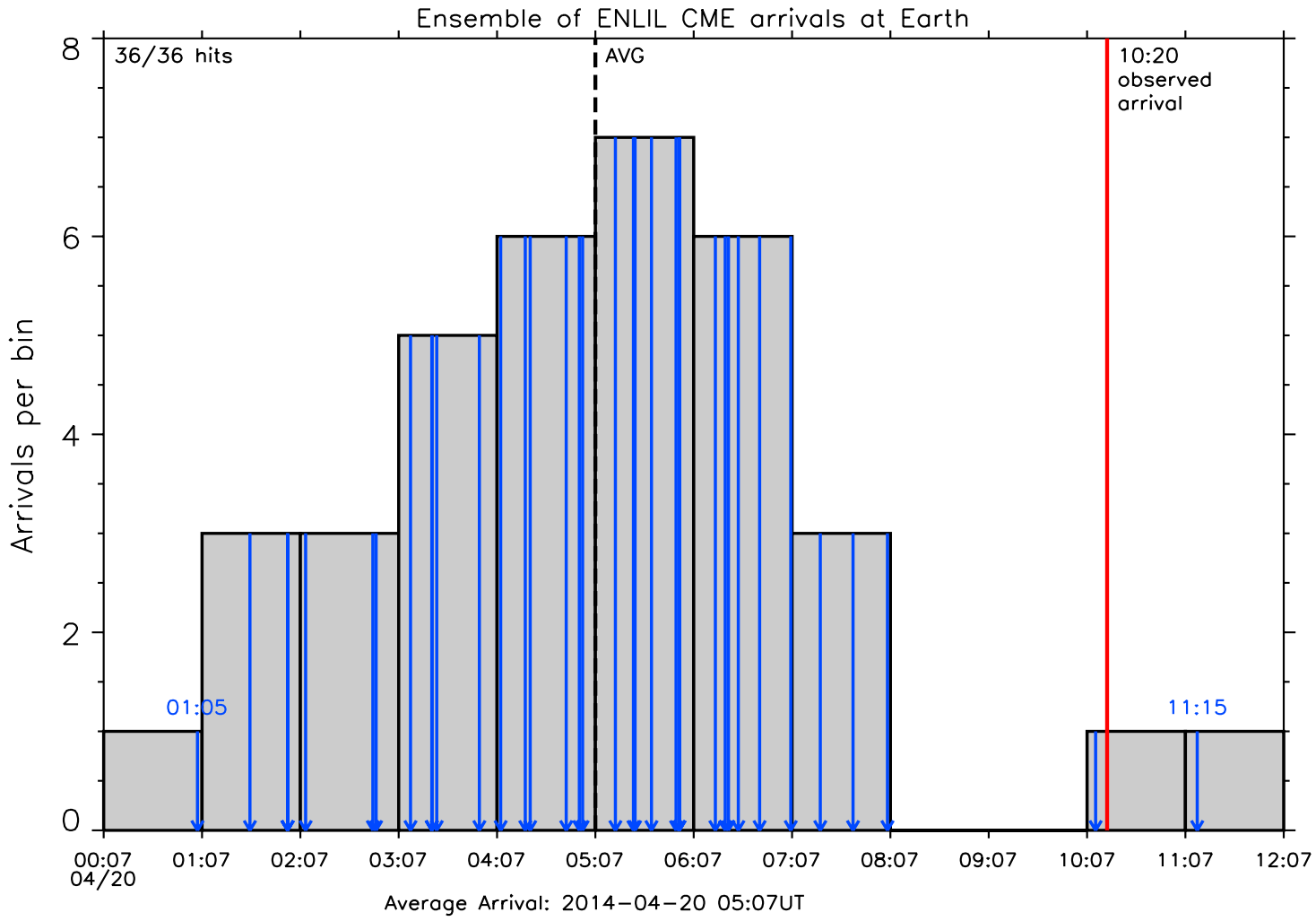


18 April 2014 CME:
WSA-ENLIL+Cone modeled magnetic field, velocity, density, and temperature profiles at Earth for 36 ensemble.



Clear ICME arrival with enhanced post-shock temperatures, enhanced magnetic field with rotations in direction, and declining solar wind speed.

18 April 2014 CME: Histogram distribution of arrival time predictions at Earth



-5.2 hours prediction error for average predicted CME arrival